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ABSTRACT

In a series of three half-day seminars, scientists from AT&T Bell Laboratories, IBM (International Business Machines), and the Corporation for National Research Initiatives described current research in materials science, computing, and networking with implications for scholarly communication in the future. The audience for the seminars included public administrators, educators, information professionals, researchers, and representatives from other professions whose common bond is the use or support of information for research. It is noted that the laboratory investigations of 20 years ago--in laser phenomena, light-conducting media, digital data organization and transmission, ceramic properties, to name just a few areas--are now commonplace in the technology of fiber optic networks, satellite communications, packet switching, microminiaturization, and other transformations of the methods and environment of our work. It is the assumption of the conference series that current research will just as profoundly alter the future. This report addresses organizational, financial, facilities, and personnel policy responses to the challenge posed by the information science revolution in the conduct and management of research. (DB)

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**TECHNOLOGY
AND THE
RESEARCH
ENVIRONMENT
OF THE FUTURE**

**The Impact of the Information Science Revolution
on the Research Environment of the Future**

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Jerome Yavarkovsky is Director of the New York State Library. Prior to that, he was Dean of Libraries at Adelphi University. Mr. Yavarkovsky was previously head of the Systems Office at the Columbia University Libraries before becoming Assistant University Librarian at Columbia from 1972 until 1983.

Mr. Yavarkovsky earned an M.S. in Library Service from Columbia University, and an M.S. in Industrial Management from the Massachusetts Institute of Technology. He has a Bachelors of Mechanical Engineering degree from Rennselaer Polytechnic Institute.

**TECHNOLOGY AND THE
RESEARCH ENVIRONMENT
OF THE FUTURE**

**THE IMPACT OF THE INFORMATION SCIENCE REVOLUTION
ON THE RESEARCH ENVIRONMENT OF THE FUTURE**

FEBRUARY 1989

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THE IMPACT OF THE INFORMATION SCIENCE REVOLUTION ON THE RESEARCH ENVIRONMENT OF THE FUTURE

ABSTRACT

TECHNOLOGY AND THE RESEARCH ENVIRONMENT OF THE FUTURE

In a series of three conferences sponsored by the New York State Library and the Nelson A. Rockefeller Institute of Government, scientists from AT&T Bell Laboratories, IBM, and the Corporation for National Research Initiatives described current research in materials science, computing, and networking with implications for scholarly communication in the future. The audience for the conferences included public administrators, educators, information professionals, researchers, and representatives from other professions whose common bond is the use or support of information for research.

The laboratory investigations of 20 years ago—in laser phenomena, light-conducting media, digital data organization and transmission, ceramic properties, to name just a few areas—are now commonplace in the technology of fiber optic networks, satellite communications, packet switching, microminiaturization, and other transformations of the methods and environment of our work. It is the assumption of the conference series that current research will just as profoundly alter the future.

This report addresses organizational, financial, facilities, and personnel policy responses to the challenge posed by the information science revolution in the conduct and management of research.

1.0 PREAMBLE

In the fall of 1987, Commissioner Thomas Sobol of the New York State Department of Education and Acting Chancellor Jerome Komisar of the State University of New York launched an investigation of the possible impacts of the information sciences revolution on the research environment of the future. Because they both have overarching responsibilities for New York State's research environment and are aware of the rapid social transformations being brought on by emerging information technologies, the Commissioner and Chancellor challenged a group of technical experts, policy and management experts, and policymakers from state government to grapple with the question of how our research environment will be different in 15, 20, or 30 years because of innovations in basic technology either under development or forecastable now.

The New York State Library and the Rockefeller Institute responded to that challenge. A series of three half-day seminars were planned and implemented. In these three seminars bench scientists from several of this nation's premier research institutes reported on current and future developments in basic and applied research applied to information science. The three topics for these sessions were: Frontiers in Materials Science, Advanced Concepts in Computing, and The Information Infrastructure of the Future. These reports on the current research frontier were made to State level policymakers, providing a state-of-the-art preview of what the next 10 to 25 years might hold in terms of basic advances in information technology.

In addition, a panel of experts in the field of research information management and policy was assembled to hear each of the three sessions featuring bench research scientists. This "blue ribbon" panel was charged with discerning the policy and management implications of the more basic scientific presentations for the management of the research enterprise over the next 10 to 25 years. This panel was charged to forecast what changes in the organization should occur: in financial and human resource support; in the legal and regulatory environment; and in technological and facilities planning, which would prepare New York State's research community to meet the challenges posed by rapidly breaking technological innovations.

This document is a report to Commissioner Sobol and Chancellor Komisar from this overall effort. The appendix contains the charge to the Advisory Panel. The summaries below are designed as "policy synopses."

The report concludes that basic technology will continue to challenge policies and management strategies for New York State's research community. The nature of that challenge is briefly characterized. Finally, the report attempts to detail what management and policy changes should begin to be undertaken if New York State is to maintain the competitive vitality of its research community in the face of the information science revolution. The policy responses needed now or in the near future are divided into four categories: Organizational Responses; Financial Responses; Responses in Terms of Technology and Facilities; and the Human Dimension of the Challenge.

2.0 SUMMARY OF TECHNICAL PRESENTATIONS

2.1 Frontiers in Material Science (September 15, 1987)

Dr. Al Cho surveyed recent developments in semiconducting materials with particular emphasis on the implications of those developments for communications technologies. He noted that lasers made possible by laboratory semiconducting materials promise enormous increases in the capacity and efficiency of light wave communications technologies in the next 10 years or so. He expressed his belief that this research and development will lead to cost-effective communications networks that operate at a rate of at least one billion bits of information per second. By way of comparison, he indicated that contemporary communications networks rarely operate cost-effectively at a rate above 10 million bits per second for voice or data, or at a rate above 45 million bits per second for television.

Dr. David McCall explored the numerous ways in which polymer chemistry has functioned to provide key enabling materials and technologies for the information sciences revolution. He explained the use of polymers in the fabrication of the logic and memory chips which can meet the many difficult environmental and performance requirements of contemporary and future telecommunications. He indicated his belief that a number of fundamental technological limits are already in sight and that research on methods of micro-miniaturization will soon be overtaken by research on the organization of computer and communications circuits.

Dr. Robert Dynes assayed the rapidly advancing front of research into superconducting materials. He commented that prior to December 1986 the study of superconductivity was widely regarded to be a mature science with a steadily if slowly progressing body of new findings. He then noted that over the last year or so materials have been discovered which are capable of superconduction at temperatures which previous theories predicted would not be achieved until the year 2190. He cautioned that contemporary research is no longer grounded in theory and that many reported results do not stand up upon replication. Nonetheless, he expressed his belief that the end of the current explosion of research and engineering will be major improvements in energy, computer, and communications technologies and systems.

2.2 Advanced Concepts in Computing (February 2, 1988)

In his introduction and overview of the future of information, Dr. Abraham Peled noted that our predictions about the types of machines that will be available 10 to 15 years from now may be reasonably based on prototype development work being done today in research laboratories.

Miniaturization has driven the whole industry, and is based on decreasing the size of a chip and increasing its density. It is the density of the chip which determines its computing power and memory capacity. As this trend of rapidly increasing density continues, storage of information electronically will become less expensive than paper and will provide far more flexibility and ability to access the data.

At the same time, advances in fiber optics have made it possible to transmit 1-1/2 million bytes per second along today's high-speed networks. This compares with the 56 thousand bytes

per second of 10 to 15 years ago, and an expected capacity of 45 million bytes per second in the future.

There are two basic types of computing that will evolve differently out of the massive amounts of computing and capacity that we will have available. The first is enterprise-wide computing, designed for systems requiring access to shared data. An operating example is that of an airline reservation system. The major computing capacity is not used for calculations of available seating. The computing goes into providing access to that shared data, and making it consistently available with high integrity to each user.

The second type is individual computing. The essence of this type resides in raw computing power, which can assist an individual in analysis and design. Millions of computations per second will enable the individual to spend less time in laboratories and more time on simulations. With many more iterations on the computer, the individual will be able to devise and test many more designs than previously.

Much of the increased computing capability will come from parallel systems where work will be divided among the components. Processors will be arranged in parallel for different purposes in different numbers. Many different combinations are being tested, at present, to determine what kind of problems and bottlenecks may develop. One set which is being worked on may be said to be a physics instrument. Intended to compute the map of the proton from elementary calculations, it would take between 50 and 100 years on the fastest computers currently available. With a parallel system, that same calculation could be accomplished in three months to a year.

In contrast to the advances in computing in large scale systems, Dr. Ellozy discussed the development of more personal user-friendly possibilities. Pointing out that novel ideas, concepts and experimental prototypes have become the norm over time, he explained that each step in the evolution of computing has led to increased interactivity. Systems have gone from interactive to extensible to cooperative, to intelligent, to visual, to auditory, to tactile, and to kinesthetic.

As his example, Ellozy presented the pencil and paper interface. By using large area liquid crystal displays and transparent digitizing tablets, it has become possible to create a device on which we can write and see the electronic ink display while the machine performs recognition of the activity. If these abilities are combined with written gesture and handwriting recognition, we have an ideal situation for a pencil and paper interface.

This would involve use of a computer terminal that will display information and that can understand individual markings or handwriting. System complexity would increase with cursive characters, or mixed cursive and discrete characters. It could be used for math writing as well as for music writing and would be far superior to keyboard methods, because this is the way mathematicians and musicians actually work. One can extend the benefits if a synthesizer were connected to a music writer, resulting in instantaneous playback from written music. A great advantage of such a system is increased productivity through compact natural notation.

Professor Yechiam Yemini focused his remarks on the new scale of interconnection that comes from the confluence of computing and communication, the emergence of enterprise computing, and the opportunities and risks that emerge from mass computing.

Using examples from early phases of industrial development, he described the new speeds at which we will be able to transmit and store data, envisioning the "liberation of disc farmers." It will be possible to build very powerful database machines, reading and writing directly from the stretched wires. The major problems in these situations will be the dissonance emerging from the software: we cannot process as fast as we communicate and so it becomes a conflict of transfer protocol versus bottleneck processing.

The emergence of enterprise computing is based upon proliferation and interconnection of many computers and many users drawing upon a vast amount of shared information. In attempting to conquer the problem of scale by refining mass information processing, we are redefining competitiveness by recognizing information as the principal asset. Enterprise computing systems become the fundamental tool for manufacturing, distributing, and applying this asset.

It follows then that a new role for libraries will emerge. A national library, engaged in the preservation of knowledge, could be based on enterprise computing. Organizing and sharing information resources, it would provide equal and unified access to its resources for education and research.

Dr. Daniel Sabbah defined artificial intelligence as "what we don't know how to do in computer science." The goal is to amplify human knowledge and problem-solving abilities. Using the example of a biological matrix, he pointed out that, as in many other fields, there is a flood of uncoordinated, undigested results from biological studies. Related research results leading to the discovery of new generalizations and laws are being missed. Therefore, a matrix proposal has been made to create a database of databases for the purpose of organizing and processing research results in all aspects of biology.

A system of intelligent indexing will make it possible to ask the database questions like: "has anyone done detailed biochemistry research on compound X?" and "what is important and new in the field of X?" Database queries would provide answers to different types of questions, ranging from the purely technical (how many peptides are known with characteristic X?) to those related to policy decisions (are there more than 20 labs working on X?).

The database conceived through artificial intelligence is intended to help us convert "information" into "knowledge."

2.3 The Information Infrastructure of the Future (May 6, 1988)

Keith Uncapher opened the colloquium by stating that the United States has lost the control over the world market it had prior to World War II. Moreover, as the world has evolved from a technology-based economy in the late 1940s to a knowledge-based economy today, possession of or control over natural resources is less of an advantage than having access to information or, more importantly, knowledge. The nations of the Pacific rim, especially Japan and Korea, have taken advantage of this fact and are or may soon become the economic world leaders.

For the U.S. to regain the edge in competition, Uncapher believes it is imperative that "tighter links" be developed between the university and industrial communities. The "knowledge in the heads" of those who design new products, those who manufacture them,

and the above-the-floor managers, must have a way to interact. This, according to Uncapher, can be done by storing this knowledge in computers and then exchanging that knowledge over a computer-based infrastructure.

Dr. David Clark described the evolution of The Internet, a project that has proved to be the seminal development in computer-based infrastructures. The project, begun in 1973 at the Advanced Research Project Agency, was designed to address a logistics problem: people and the information they want are not usually in the same place.

Networking hooks people to information and, more importantly, it hooks people with information to other people with different or additional information. The ultimate result is increased productivity as individuals build on the work of colleagues and transmit what they have heard through The Internet to other colleagues.

The Internet has led to an increase in research collaboration as a result of two concrete developments of the project: electronic mail and electronic publishing. A third method of computer collaboration—teleconferencing—is currently in the early stages of development.

Those working on the project now are striving to make it bigger and faster. Presently, The Internet serves the university and computer sciences communities and the federal government. Since he believes "communication is a fundamental part of human behavior and using computers to mediate this communication permits new and very powerful patterns of interaction," Clark would like to see The Internet expand until it provides service to the owners of the 200,000 telephones in the United States.

Faster service is being developed because it is "possible" and "needed." It is possible because fiber optic communication lines are faster, more economical, and more efficient than wires; it is needed because faster transmission is required to send images from computer to computer over a nationwide network than is required to send text, and transmission of text-and-images documents is a wave of the future.

Dr. Vinton Cerf expanded upon Clark's idea of using a computer system to connect people to each other and to information in what he perceives as a gigantic digital library that, in theory, can contain all information—text and images—that can be digitized.

The digital library—which is still basically in the conceptual stage—employs knowledge robots, or "knowbots," which move from one computer to another in the network, meeting with other knowbots to "mine the knowledge bases" and answer queries.

The digital library as envisioned by the computer scientists at NRI will become a reality when:

- libraries have evolved to contain all the information people need in every format (paper, film, records, etc.) available;
- the system can accept a general query in natural language and is able to determine where it can locate the answer and what mechanism(s) it should employ to get it;
- the system is able to protect the intellectual property rights of individuals by displaying the information only to those who have paid for it or have a right to it;

- the software (knowbots) is portable so that as hardware is upgraded or replaced, the system is not rendered obsolete; and
- standards are developed and adopted.

Cerf envisions a three-dimensional digital library into which one could "step." From the vestibule, one would enter "rooms" and peruse "shelves" of materials. This could be accomplished by using panning, zooming, and other techniques presently being used in computer-aided design.

Using the teleconferencing ability mentioned by Clark, one could "meet" fellow researchers in a room at a specific library. All this would be accomplished by WYSIWIS (What you see is what I see) technology, which still needs to be developed.

The entire digital library concept is built on the presumption that everyone will have his own personal digital library, which will be connected to the world of libraries, and that one will be able to send knowbots—or at least queries—from system to system along the communications infrastructure.

In order to put very high speed networks in their historical context, Dr. Robert Kahn opened his talk by summarizing what the information processing world looked like when a packet-switching network was being designed in the 1960s and early 1970s. He noted that computers were "very expensive," time sharing and batch processing were the mode of operation, workstations and personal computers were unknown entities, microprocessors had just appeared and few people knew what to do with them, local area networks did not exist, packet-switching was highly suspect, and there were no protocol standards.

With a successful demonstration of computer networking in October 1972, packet switching became the mainstay of the communication industry and researchers turned their attention to experimenting with the elements now at their disposal to see what they could develop. Among the first unplanned but soon-to-be operational results of computer network research were the electronic mailbag, internetting, the domain system, packet satellite and packet radio, local area networks, end-to-end manually keyed security and a multimedia system.

The unfinished agenda includes designing very high speed networks and efficient internetting and being able to transfer large databases over those networks.

The goal is to develop a national research and development network that will link the networks operated by the National Science Foundation and the federal government, including NASA, DoE, and DoD, to the entire scientific research community and eventually the rest of society. This backbone will be interconnected through gateways and each component will operate at the same speed (at least one gigabit per second by the turn of the century).

If funds are appropriated, Kahn sees a system in which 100,000 billion to 200,000 billion bits of information per second are sent over a single fiber, and the worst-case latency is one-tenth of a second from transmittal to receipt of information between any two computers anywhere in the United States. Moreover, 80 percent of all information sent at any given time will arrive at its destination, the key resources will be available at least 98 percent of the time, and the backbone connectivity will be at least 99.5 percent.

However, he noted that the network only will be as useful as the applications developed around it. These applications include the digital library system, a knowledge bank for science and engineering, and a medical exchange.

In conclusion, he said that he believed that networking is the core of the information infrastructure of the future and its single most important application is the fact that it "gets people working together."

3.0 TOWARD POLICY IMPLICATIONS DRAWN FROM THE TECHNICAL PANELS

Taken together, the three colloquia yielded several important implications for policies related to management of the research environment.

- Hardware advances have fueled the information science revolution over the past three decades. New hardware systems have spawned new generations of increasing user-friendly software, and hence have expanded applications. At least for the past two decades, basic advances (especially in the design and manufacturing of semiconductor devices) have led this advance in hardware systems. One important aspect of these advances has been exponentially decreasing costs for computational machines. A second important aspect of these advances centers on dramatic increases in telecommunications capacity at exponentially decreasing costs.
- Basic research into semiconductors and other basic materials suggests that these dramatic advances will continue for at least the next 20 years. That is, given the current state of basic science and development research, new hardware-driven innovations will continue to reach the market at the same exponentially growing pace over the next twenty years similar to the growth of the past twenty years. One implication of this conclusion is that it is likely that current mainframe capacity will be available in a desktop machine at current PC prices in the near future.
- Given the cost and technology curves, intelligent devices will appear in many places within our research environments where they do not presently appear. Communications systems linking information nodes within laboratories, publishing houses, libraries, and media and communication systems will be rapidly developing.
- Current research into superconductor devices is in the infant stage, but has a very promising future. The current performance of superconductors has outstripped what has been predicted by existing theory. This suggests that basic research into material science has no experimental results that contradict theoretical predictions leading to the possibility of a theoretical revolution in our understanding of conductivity (super and perhaps other types of conductivity). Such basic advances could insure continued exponential advances in new technologies to the marketplace beyond the time frame indicated by improving the already established and traditional semiconductor research and development.

4.0 THE POLICY AND MANAGEMENT CHALLENGE FACING MANAGERS OF THE RESEARCH ENTERPRISE IN NEW YORK STATE

Recently, research institutions have recognized that the information revolution is rapidly changing the way that basic and applied research is organized and executed. For example, new organizational units not in existence 20 years ago are common in most organizations. The financial infrastructure of many research projects has tipped dramatically in favor of acquiring and maintaining information processing equipment. How we build research facilities and how we install basic equipment is changing literally from year to year. Finally, policies on hiring, training, and maintaining the technical competency of a research staff and research support staff is becoming an urgent and costly issue.

In addition, as New York State grapples with these issues, so do other states. That is, to a certain degree, New York is engaged in a competitive situation as it strives to respond to the many and diverse challenges to keeping its research environment at the cutting edge. Furthermore, keeping research competitive is no longer the arcane concern of research scientists alone locked in their labs. Powerful experiences in eastern Massachusetts, California's Silicon Valley, and North Carolina's research triangle suggest that the competitiveness of a region's research laboratories may be the key to its continuing economic vitality.

In the sections immediately below we pose the following questions: Who are the managers of New York State's research enterprise who should be engaging these questions? What is the scope of the policy and management challenges that are posed by the information science revolution? Finally, how can managers and policymakers begin now to respond to those policy and management challenges?

4.1 Who Are the Managers of the Research Enterprise?

In one context, many groups could be identified as having lead roles to play in managing the impact of the information science revolution on New York's research environments. Educators will play a significant role in training future researchers. Directors of libraries and computing centers will play an important role in installing information systems to support research laboratories. Managers of the state's telecommunications networks and systems will play a lead role in connecting isolated information islands. Publishers and media managers will play a decisive role in determining how research results are disseminated both to the research community as well as to the public at large. Of course, formal networks of researchers (such as professional societies) as well as less structured and informal networks will define how information flows through the research community. In a very real sense, all of these actors are the policymakers and managers involved with shaping New York's research enterprise over the next several decades.

However, for purposes of this report, we focus on a more sharply defined audience. Certain key individuals will play an exceptionally important role in shaping institutional responses to challenges to New York research communities. These are the chief operating officers of institutions with a primary research mission. These chief operating officers traditionally employ a large cadre of professional research scientists, deploy budgets to support libraries, computing centers, distributed information systems within laboratories, and

telecommunications facilities, and have broad responsibility for organizing research centers and maintaining a well-trained and up-to-date work force. Examples of such managers are presidents of public and independent research universities, the Commissioner of Education, the Chancellor of the SUNY or the CUNY system, or the directors of privately financed research and development facilities. These chief operating officers form the primary audience for this report.

4.2 The Scope of the Policy Challenge

Given the exciting scope and vision of the presentations on basic research, it is difficult to forecast precisely or even to get a broad brush view of what technological capabilities will reach the marketplace in the next 10 to 25 years. However, it seems apparent that technology will continue to outstrip the ability of our organizational, financial, human resource, and physical support systems to respond to those innovations. In particular, hardware technology is advancing so rapidly that software quickly becomes obsolete and must be redeveloped. Yet our institutions are not adequately staffed or budgeted to perform this necessary redesign and rebuilding in parallel with ongoing system operations and maintenance. Furthermore, the laws and regulations currently in place and governing commerce and the research enterprise are constraints on flexibility and responsiveness. Finally, the social and human dimensions of the research environment must be in a position to sort out the useful from the flashy innovations and to invest prudently in those technologies that hold most promise.

In order to provide a point of reference for further thinking, we will frame several rather simple but plausible assumptions from which to begin discussion. First, we assume that every researcher (who so wishes and with financial or institutional means) will be able to have a private computing machine dedicated to his or her own research interests that has the computing power of a present day mainframe. This machine will probably be much easier to use than present day mainframes and will be priced as are microcomputers today.

Second, it seems reasonable to assume that all of these machines located within individual labs can be connected via a fully integrated communications system with easy-to-use interfaces. That is, full-point connectivity could create a virtual worldwide network of users. Furthermore, these networks will also contain as nodes libraries and publishing centers.

Third, systems will exist to provide full access to complete information records within research labs, within libraries, and within publishing centers. That is, current information retrieval systems contain pointers to where full information is stored. These future information systems could provide full textual, audio, or graphic information records.

The implication of these three assumptions is that it will be technologically possible to create an information environment where researchers have full access to broadly defined information bases of other researchers, material in libraries, and information in publishing centers from their personal mainframes.

4.3 How Can We Respond Now?

Of course, numerous financial, social, and human factors may prevent the implementation of this assumed vision, including the commercial, political, and military value of information in

the resulting network. However, the challenge to managers today is to begin to envision what are the financial, organizational, human resource, and physical facilities policies changes that can move New York's research community forward to meet constructively the challenge posed by this technologically possible future.

In its deliberations, the blue ribbon advisory panel has discussed what policy and management steps can be taken to best position New York State to face these future challenges. The results of that panel discussion are presented in the four sections below.

5.0 ORGANIZATIONAL RESPONSES

Two principal organizational responses emerged from the panel discussion: selecting technology for use; and organizational governance and structure.

In selecting information technology, research institutions must adopt strategies for information technology initiatives that recognize the international nature of the research enterprise, and pursue directions that exploit relationships beyond their regional and even beyond their national boundaries. An organizational self-image reflecting progress, change, and growth has been identified with the successful use of information technology, suggesting that there is indeed a particular advantage in recognizing and promoting the institution's global importance and connections.

Acknowledging that organizations will not be able to absorb every technological innovation, it is essential that older technologies be dropped and that irrelevant or fashion-driven technologies also be identified and avoided. For example, the growth of commercially available smart software encourages companies to use software with built-in assumptions that might not be appropriate to them. It is important that software be matched to the realities of the environment where it will be used and that the inevitability of system obsolescence be recognized.

In regard to governance and structure, the profound impact of information technology on organizations demands administrative arrangements and procedures flexible enough to support the transition from current to future systems. Intrinsic to this flexibility is the empowerment of employees to participate in decisions relating to technological systems they will use.

Employees will become geographically dispersed, working at home or at other remote sites. This poses a greater challenge to foster and maintain cohesion, morale and identification with the employer as an entity or institution. It also presents challenges of supervision and quality control. This evolution towards greater independence and greater employee self-determination must be factored into the structure and governance of future organizations and into the way work itself is designed.

Information technology resource centers, technology advisory committees, designated chief information officers, explicit information policies, and social networks organized around access to information are several ways for organizations to facilitate end-user computing and the progress towards truly pervasive use of information technology.

6.0 FINANCIAL RESPONSES

Prominent among the observations of the advisory panel was the importance of management perceiving information technology as an investment rather than a cost, recognizing the asset value of the technology and, perhaps more important, the asset value of intellectual property contained within information technology. This is especially necessary in an environment of rapid change and high cost, demanding frequent and often creative approaches to financing even in the absence of clear cost benefit relationships.

Traditional funding sources and levels are not sufficient to finance networks and databases on the scale already necessary. There must be an increase in the variety and structure of revenue sources, including collaborative approaches, and mechanisms for allowing an increased level of risk in technological innovation. The tendency to buy "sure things" results in buying obsolete technology, and some risk is necessary to exploit advanced technology. On the other hand, indiscriminate acquisition of information and technology does not necessarily improve decision making. It is essential that the institutional use of technology over time and in different environments be reviewed and evaluated to assure efficient use and acceptable return on investment. Underpinning this, sound depreciation policies and equipment and system replacement policies are necessary, as is sufficient budget for equipment maintenance.

In regard to budgeting and management, it is imperative to foster practices that facilitate the procurement and effective use of information technology. Purchasing procedures should be routine, rather than requiring special attention relative to other procurements. There should be funds for periodic technical advice, and flexibility in the use of funds as hardware and software needs arise. Funds for increased salaries and training are important so that research institutions can compete for talent and make effective use of the hardware and software investment.

7.0 RESPONSES IN TERMS OF TECHNOLOGY AND FACILITIES

Infrastructure development, system standards, human factors design, support services, planning, and system security are essential elements to be addressed in preparing for the technological environment of the future.

Technology-based networks are a key to improved research productivity and economic growth. It is important to encourage the development of telecommunications utilities, such as NYSERNET, that undergird information technology, and to create and organize appropriate networks to access information. Facilities of this kind must be developed and deployed in anticipation of the need for them, moving towards institutional sharing of facilities and cost-effective alternatives to dedicated facilities. Concomitant with this is the need to modernize institutional telecommunications and management information systems.

Standards are absolutely necessary to a cost effective future based on connectivity and shared facilities. Telecommunications standards, machine compatibility, standardized operating systems, and upload and download standards are a few of the areas where industry cooperation is to be strongly encouraged to promote and adopt common practices and linkages among systems.

The evolution towards fully interconnected systems should be facilitated by institutional support services to help users with routine tasks such as equipment and software selection, maintenance and repair, management of distributed hardware and software. These should be motivated not simply by improved productivity, but also by the desire to maintain the value of institutional investments in these facilities and in staff.

Extending the institutional responsibility to staff, it is important that the physical work environment be conducive to effective performance. Space and furnishings should be designed to accommodate the people using them. Facilities planners should be in close dialogue with operational staff, and procurement units should have human factors expertise to ensure that physical access is not impeded and that physiological demands are within human capacities.

In addition to ongoing support services, institutions need mechanisms to project and review information technology plans. Planning the integration of voice, data, and video telecommunications, and determining an appropriate level of decentralization in equipment decisions are two areas of technology planning in particular need of attention.

Finally, as dependence on telecommunications and shared data increase, the importance of assuring confidentiality grows. Data quality and integrity, physical security of data, and disaster recovery must also be planned and accommodated.

8.0 THE HUMAN DIMENSION OF THE CHALLENGE

Perhaps the greatest challenge is posed by the human resource needs emerging in the evolution towards new levels of technology in the research environment. Recruitment, training, career development, and the organization of work must all be scrutinized and directed towards improving staff performance and satisfaction and the ethical climate in which technology is employed.

It is imperative that ethical and moral considerations be included in the training for information resource management. Enormous power is held by those who control the information tools that play an increasingly important and influential role in society. The human dimension of the challenge applies not merely to the designers and users of information systems, but equally, perhaps more so, to the individuals and groups whose livelihoods and lives are in some measure governed by these systems. Judgments will be made pertaining to quality, safety, profit, convenience, and many other factors related to how systems are used and who benefits from them. The information managers making these judgments need an ethical context for decisions as well as a technical one.

Training must be conceived in terms of the need for a continuously educated workforce. Retraining should be institutionalized, along with management training for researchers and others moving into management positions but without management backgrounds.

In developing career paths, flexibility and receptivity to nonconventional jobs will be important, as a class of technological amphibians emerges, performing both traditional and new forms of work in a highly technological environment. Chief information officer is a position that has already achieved considerable importance in many organizations, yet lacks career paths leading to it. Training and opportunities should be provided to prepare

individuals for this type of role as well as for information resource management in general. Technical staff need career ladders to reward them for continued growth and contributions without necessarily requiring that they enter managerial positions. In general, policies and procedures for promotion and career advancement should foster initiative and creativity. Individual differences and learning styles should be recognized in preparing training programs.

The scarcity and competition for talented people makes recruitment more difficult and requires that institutions be aggressive in their search practices. Perhaps more important, reward structures must be revised to attract and retain excellent staff. In addition to strengthening financial rewards and opening career paths, creative benefit programs are necessary, such as child care and parent care, to reflect changing societal patterns and needs. A larger fraction of the population—women, minorities—must be drawn into the mainstream technology workforce. In academic institutions, tenure and promotion criteria should be updated in light of emerging publishing realities in a world based on telecommunications. Research products and publications that are in soft form—online, on magnetic or optical media, and in the form of databases—should be recognized as alternatives to traditional printed publications.

As employees choose more and more to work at home or at remote sites, it will be especially important for organizations to maintain cohesion and morale to avoid feelings of employee isolation. Supervision and quality control in that environment will also challenge traditional management procedures and relationships. The greater independence and greater use of computers by employees will require new attention to job definition and design, including an emphasis on sound ergonomic design for the employee workstation.

9.0 CONCLUDING OBSERVATIONS AND A SCENARIO FOR DISCUSSION

An inescapable conclusion of the seminar series and the discussions of the advisory panel is that dramatic changes are taking place in the way researchers share the results of their work and learn of the work of others, and there is the prospect of even more radical change in the future. This is consistent with observations and experience in the disciplines and industries concerned with publishing and literature control, and is becoming obvious to scholars in all fields.

Scholarly communication—the dissemination of research concepts, methodology, and results—is fundamental and vital to research. It underlies economical and effective research strategies that strive to eliminate unnecessary duplication and build on work conducted elsewhere.

Reflecting on the very basic nature of the changes the speakers foresee, and their pervasive character, the following scenario was introduced for discussion at the final meeting of the advisory panel:

TECHNOLOGY AND THE RESEARCH ENVIRONMENT OF THE FUTURE
A SCENARIO FOR DISCUSSION
JEROME YAVARKOVSKY
MAY 6, 1988

There is inevitable progress towards and a growing infrastructure to support online communication among scholars. Word processing microcomputers are commonplace in producing work in all disciplines and in preparing the results of research for publication. Online communication from one system to another already takes place among scholars in some disciplines, with researchers corresponding with each other and sharing their work and results in real time through electronic mail and bulletin board systems.

The establishments that depend on scholarly communications—universities and their component academic departments and laboratories, libraries, publishers, industrial firms, learned societies—are not organized or equipped institutionally to accommodate the storage and delivery of literature in electronic form as modes intrinsic to their operations. For example, tenure rules and procedures are based on traditional publication. Library procedures and research are based on traditional formats for making information available. Publishers issue printed journals and books. We know these conditions are changing and that the institutions we are familiar with are more and more involved with new modes and new media for access and delivery and resource sharing. Nevertheless, we see inexorable and rapid change that our institutions are unable to cope with in their policies, in their practices, and in their budgets.

What emerges is the need for a new paradigm, a new set of relationships, and new policies. For example, there is need for a mechanism to release publications for review and refereeing online, with secure and confidential controls, and then to make them available electronically online permanently for the use of researchers who need them. The EXPRES system for online proposal submission and review, currently under development with National Science Foundation funding at Carnegie Mellon University and the University of Michigan, is one possible approach. There is need for an institution or agency, or several, to take responsibility for this process, providing access and ensuring archival availability. There is also the need for academic institutions to accept online publishing in this mode for tenure and promotional proceedings. Perhaps the appropriate model to adopt is one that is inspired more by the public broadcasting system than by the conventional publishing and library acquisitions process. What it might entail is an agency—perhaps one created by libraries, or perhaps an existing agency assuming the responsibility on behalf of libraries—to be a locus of scholarly electronic publishing activity on a not-for-profit basis. The national network links now in place could be used for providing access to and distributing the resulting publications. The future telecommunications infrastructure will be even better for these purposes.

The public broadcasting model is apt if we consider the Public Broadcasting Service and its network of stations, and their relationship to independent producers and to commercial networks. Producers sell their program rights to individual stations directly; more important, they sell rights to the networks which negotiate on behalf of the stations. The negotiated arrangements take many forms, but the result is reduced marketing costs for producers, and reduced product costs for stations.

Producers sometimes sell the same programs to public stations and to commercial stations in different markets. State money is often included in the negotiated purchase, combined with network and station funds so there is a model for subvention. In some instances, programs are reviewed for quality by designated specialists in a process comparable to refereeing.

If authors and journal publishers, including learned societies, were viewed as producers, and if libraries were joined in one or more publication networks, then rights to articles or publications could be negotiated for libraries by an agreed-upon agency—the equivalent of a PBS for scholarly publishing. The role of the network/agency would be twofold: to negotiate rights on behalf of libraries, and to provide electronic publication distribution services to libraries.

Depending on the arrangement negotiated, the purchased rights would permit participating libraries to copy and use articles as necessary to meet institutional needs. Time boundaries could be applied so that recent articles might be more expensive than older articles. Blocks of articles might be downloaded and stored locally if that is useful. As with video networks, many types of arrangements might be negotiated. The designated network/agency might serve publishers and libraries in the way that broadcasting networks serve producers and stations. The network/agency would contract with learned societies or small publishers to store electronically and distribute on demand the items published. The same services might be provided for publications whose rights were negotiated for by the agency, but whose publishers might normally provide their own distribution.

The goal, in general, is not to replace commercial publishing. Instead, it is to offer authors, learned societies, libraries, universities and other knowledge institutions, and publishers themselves an alternative structure suitable to the electronic age. Copyright and royalties would apply, to compensate authors, and the network/agency would be supported by fees for use of the publications and for their services. Models for accounting and compensation exist in the music industry, advertising, and commercial television.

Discussion and subsequent correspondence from advisory panel members was supportive of the scenario and the broadcasting model. There was apprehension regarding the prospect of a true equivalent to public broadcasting because of the perennial funding problems confronting public broadcasting. The economics and financial structure of the ultimate configuration are obviously key elements to be addressed and resolved in the development of this concept. Certainly, cost justification for public funding of such an agency can be found in the benefits to education, research, and public access to a wide range of database and communication resources. Sponsorship by business and industry would be important, and consistent with the benefits to be derived by the commercial sector from the envisioned network.

The public broadcasting approach was especially appealing to some as a means to introduce public and foundation support into scholarly publishing as an alternative to continuing the traditional dependence on commercial and institutional funds. Publishers currently bear full costs of producing electronic products and receive royalties that they perceive as inadequate. Although public agency operating costs might not make it possible to pay higher royalties, a public agency should be able to help publishers find underwriters and sponsors outside the publishing industry.

There was some indication that a venture of the kind described in the scenario would foster closer working relations among businesses, libraries, and schools. The expectation is that the cooperative spirit inherent in such an enterprise would overcome the "us and them" attitude often apparent between business and the academic community.

The scenario envisions libraries playing a leading role in the establishment of online publishing mechanisms, but the issue is clearly broader than libraries. The observation was made that a national infrastructure is necessary that embraces a new and vital role for libraries as well as direct involvement of the core of the scientific and technical research community.

Another advantage of the public agency approach to research communication lies in the greater accessibility of material that might not be judged profitable enough by a commercial publisher. A public agency should be expected to be more open and flexible in its selection and distribution policies. A public online agency might also establish standards of quality for all aspects of online scholarly communication that others may follow.

It was felt that an online literature network directed towards libraries and educational institutions would open those markets to publishers who otherwise do not have access to them. Further, such a network would lower the cost of online services, making the services themselves accessible to institutions that now must minimize their online usage or have virtually no access at all because of high charges.

The history of interest in access to a central depository of scholarly publications dates back at least to the Royal Society Scientific Information Conference, 21 June–2 July 1948, and the paper by J. D. Bernal, "Provisional Scheme for Central Distribution of Scientific Publications." The technology is now available to implement such a scheme, and the scholarly publishing marketplace, characterized by rapidly increasing costs and diminished subscriptions among libraries, militates strongly in favor of alternatives to traditional journal publication. Hence, the scenario seemed to present a strategy for implementing an idea whose time had come.

Among the advantages noted for collaboration and online communication among scholars was increased research productivity. Even among corporate researchers, where proprietary interests tend to discourage information sharing, the use of electronic bulletin boards, computer conferencing, and electronic mail systems is resulting in greater openness and greater productivity. Given the importance of research to economic development and to the creation of new economic opportunities, the improvement of research productivity through infrastructure investment is essential.

Easy and low-cost access to computer-based networks by virtually the entire research community—academic, industrial, and government—was seen as a national priority of the utmost importance. This would facilitate collaborative work by scholars regardless of location, continual sharing of innovation and sharing of resources, resulting in an amplification of the national intellectual capacity and a reduction in technological development time.

10.0 SUMMARY OF RESPONSES TO THE CHANGING ENVIRONMENT

- (1) Provide planning funds to track new developments and guide public investment in new technologies.
- (2) Invest in physical infrastructure development and installation for telecommunications.
- (3) Encourage software development to facilitate intersystem communication among researchers and scholars.
- (4) Support the development of standards for system interconnection.
- (5) Provide incentives for the diffusion of technology throughout government, business, and education.
- (6) Promote the creation of new organizational arrangements and new governance structures to facilitate the exploitation of new technologies.
- (7) Expand the concepts of intellectual property to accomodate new technologies and reward creativity.
- (8) Revise university tenure and promotion criteria to accept electronically stored and delivered publications.
- (9) Foster the establishment of publication networks based on electronic storage and online access.
- (10) Encourage organizational flexibility to facilitate employment at home or at other remote sites.

APPENDIX I

CHARGE TO THE ADVISORY PANEL ON TECHNOLOGY AND THE RESEARCH ENVIRONMENT OF THE FUTURE

The Advisory Panel on Technology and the Research Environment of the Future will attend three conferences on knowledge transfer in 5 years, 10 years, the year 2000, and beyond, and reflect on their implications for:

- the process and form of scholarly publication;
- the time frame, methods, and content of research;
- the nature and structure of research institutions;
- training specific to the conduct of research;
- changes in learning and teaching methodologies;
- the education of policymakers and decisionmakers;
- the architecture and facilities of the workplace.

The Advisory Panel will address the following questions, among others:

- What might research communications look like by the year 2000? What are the implications of changes in scholarly publication?
- How should we be preparing now for technological changes in scholarly and research communications and information transfer in the year 2000?
- Will the subject matter of research be influenced by new methods and changed time parameters?
- Will new research evaluation standards be necessary, given the immediacy of publication (the shortened time span between conceptualization and dissemination) and possible changes in peer review as we now know it, or changes in the entire review process as we now know it?
- What are the implications of altering the time and space between researchers and their data sources, scholars and their literature sources, authors and their publications?
- What are the implications for universities, libraries, learned societies, and other scholarly institutions, of changes in the time span of research and publication?

APPENDIX II

NEW YORK STATE LIBRARY – ROCKEFELLER INSTITUTE OF GOVERNMENT

ADVISORY PANEL ON TECHNOLOGY AND THE RESEARCH ENVIRONMENT OF THE FUTURE

John H. Marburger III
President
State University of New
York at Stony Brook
Advisory Panel Chairman

Millicent D. Abell
University Librarian
Yale University

Henriette D. Avram
Assistant Librarian for
Processing Services
The Library of Congress

Gregory M. Benson, Jr.
Director
Center for Learning Technologies

Henrik N. Dullea
Director of State Operations
Policy Management
New York State Executive Chamber

Jean-Paul Emard, Vice President
of Administration and
Advertisement
Meckler Publishing Company

Glyn T. Evans
Assistant Vice Chancellor for
Library Services
State University of New York

Frank Farrell
President
Grolier Electronic Publishing

Eugene Garfield
President
Institute for Scientific Information

Stanley Katz
President
American Council of Learned Societies

James Meindl
Provost
Rensselaer Polytechnic Institute

W. David Penniman
Director
Libraries and Information Systems Center
AT&T

Paul Evan Peters
Systems Coordinator
The New York Public Library

David H. Stam
Director of Libraries
Syracuse University

Edward Sullivan
Member of the Assembly
State Of New York